Science AAAS

Dating Pharaonic Egypt

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Science **328**, 1489 (2010);
DOI: 10.1126/science.1191410

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and introduced climate feedbacks.

Over the past 3 million years, the climate feedbacks have amplified the response to obliquity forcing and have also accelerated the cooling trend that started much earlier. The obliquity cycles are evident in SST changes in the eastern and western equatorial Pacific. The cooling trend, however, appears only in the east, not the west, so that the SST gradient along the equator in the Pacific increased as we approached the present. This difference between the eastern and western Pacific is a consequence of a long-term shoaling of the thermocline; because of its downward slope to the west, it affected SST strongly in the east but not the west. Superimposed on this trend were vertical oscillations of the thermocline (see the figure, panel B). Obliquity cycles at times caused the thermocline to be sufficiently shallow to affect SST all along the equator, in the east and west. At such times, the tongue of cold water along the equator stretched far west of the dateline. The thermocline has a complex spatial structure and, even though it can be shallow all along the equator, it usually remains deep near 4°N. That is why measurements that cover the last ice age, across the equator along 95°W, show practically no change in SST at 4°N but large changes at the equator and further south (*9*). (A section across the equator in the far western Pacific, to determine whether SST changes there are similar to those along 95°W, would be valuable.)

The observations of Martínez-Garcia *et al*. (*3*) and of Herbert *et al*. (*4*) corroborate the hypothesis that oceanic links can translate obliquity forcing in high latitudes into SST response in low latitudes, but several questions remain unanswered. Researchers have thus far considered the waxing and waning of glaciers, and the SST fluctuations in the tropical Pacific, as two unrelated facets of the response to obliquity variations. The challenge now is to determine how the two facets are connected, and why, over the past 0.7 million years, cycles of about 100,000 years became dominant. Further questions concern the effect of variations in the atmospheric concentration of carbon dioxide on climate. The arguments of Herbert *et al*. (*4*), which suggest that this greenhouse gas played an important role in producing similar tropical SST variations in different regions, are undermined by the striking differences between the eastern and western equatorial Pacific, between the regions north and south of the equator along 95°W, and between the equatorial Pacific and Atlantic. In the Atlantic, obliquity signals appear to be secondary to those induced by precession of Earth's axis, for reasons yet to be explored.

References and Notes

1. J. Zachos *et al.*, *Science* **292**, 686 (2001).
2. About 3 million years ago, surface waters cooled in the tropics, zonal SST gradients were established along the equator, and the tropical pool of warm surface waters contracted in the north-south direction (meridionally), but the precise timing varied from place to place (*3*–*6*).
3. A. Martínez-Garcia *et al.*, *Science* **328**, 1550 (2010).
4. T. D. Herbert *et al.*, *Science* **328**, 1530 (2010).
5. C. M. Brierley *et al.*, *Science* **323**, 1714 (2009).
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8. The threshold about 3 million years ago signaled a change in how the ocean absorbed heat in the tropics and transported it poleward. Previously, vertical mixing (perhaps involving hurricanes) was important. Afterward, the wind-driven circulation acquired a meridional overturning component with much stronger upwelling at the equator (*10*).
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10.1126/science.1189748

ANTHROPOLOGY

Dating Pharaonic Egypt

Radiocarbon dating and modeling of Egyptian dynasties are strengthening the links between historical chronology and archaeological associations.

Hendrik J. Bruins

Ancient literary sources of Pharaonic Egypt constitute the historical cornerstone of time in the eastern Mediterranean region during the Bronze and Iron Ages (the third to first millennia B.C.E.). Historical chronologies for ancient Egypt are based on abundant but fragmentary written sources, and various chronological interpretations exist (*1*–*5*). Radiocarbon dating has the potential to verify those interpretations (*6*). On page 1554 of this issue, Bronk Ramsey *et al*. (*7*) present a comprehensive and sophisticated radiocarbon dating study on the chronology of Pharaonic Egypt, involving 211 samples. The short-lived plant samples for ^{14}C dating were selected from individual funerary contexts in various museum collections. Each sample could be associated with the reign of a particular Pharaoh or with a specific section of the historical chronology.

Bronk Ramsey *et al*. developed three separate multiphase models for each major period—Old Kingdom, Middle Kingdom, and New Kingdom—to obtain high-precision ^{14}C chronologies. The ^{14}C model results for the Old Kingdom have an average calendrical precision of 76 years and correspond with the historical consensus chronology according to Shaw (*4*). The Middle Kingdom results have an average calendrical precision of 53 years, also favoring the conventional historical chronology. The New Kingdom results, based on 128 ^{14}C dates with an average calendrical precision of 24 years, however, do not support the younger (low) historical chronology options (*1*, *5*), but are nearest to the consensus chronology (*4*) with the 18th Dynasty beginning in 1550 B.C.E. The model actually favors a slightly older beginning of the New Kingdom at ca. 1560 B.C.E.

The enormous volcanic eruption at Santorini in the Aegean Sea during the Late Minoan IA period (*8*, *9*) is a key stratigraphic time marker in the eastern Mediterranean region during the second millennium B.C.E. However, a vexing time difference exists of ~100 to 150 years between archaeo-historical dating and radiocarbon dating of the eruption (see the figure).

Concerning ^{14}C dating, how do the new results for dynastic Egypt (*7*) relate to the Minoan Santorini eruption? The most precise radiocarbon date of the eruption is 1627 to 1600 B.C.E., obtained by wiggle matching of a sequence of ^{14}C-dated tree rings from an olive tree found on Thera, buried in tephra (*10*). Radiocarbon dates from the archaeological site of Akrotiri (Thera) (*8*) on short-lived plant remains related to the Minoan Santorini eruption yielded an average date (uncalibrated) of 3350 ± 10 years before the present (^{14}C yr B.P.) (*11*). Remarkably similar ^{14}C dates were obtained from Crete on animal bones found at Palaikastro in Late Minoan IA context with volcanic ash of the Minoan Santorini eruption and related tsunami deposits: 3350 ± 25 yr B.P. along the promontory and 3352 ± 23 yr B.P. at the inland archaeological site (*12*). By comparing these ^{14}C dates (*10*–*12*) with the new radiocarbon-based chronol-

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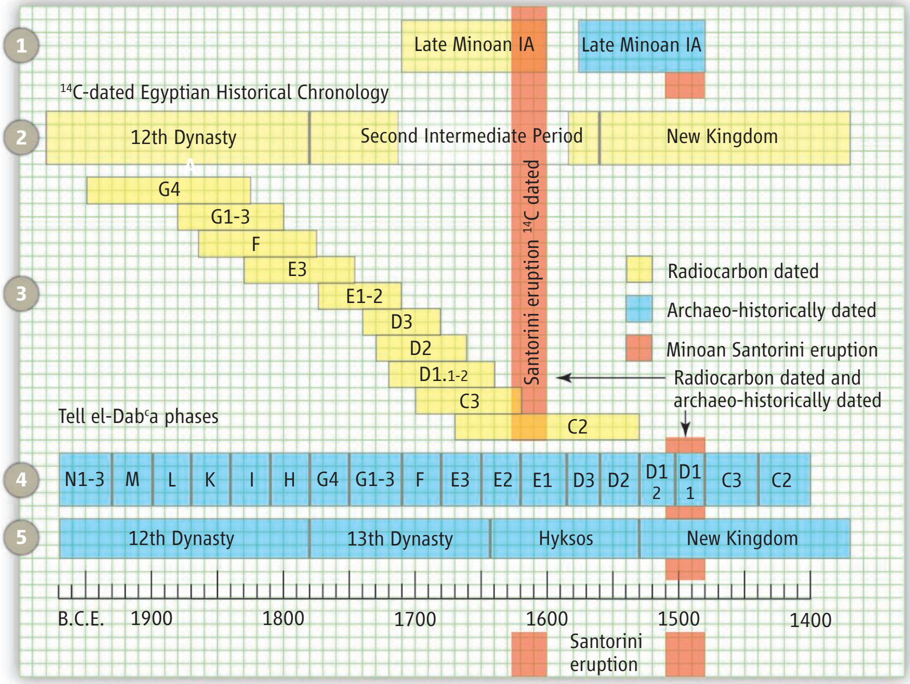

Setting on a date. Dating and association complexities regarding Egyptian dynastic chronology in the second millennium B.C.E. From top to bottom: (1) Radiocarbon dating (yellow) (*16*) and archaeo-historical dating (blue) (*13–15*) of the Aegean Late Minoan IA period in relation to the ^{14}C-dated (*10*) and archaeo-historical dated (*13–15*) Santorini eruption (red). (2) The new radiocarbon and modeling results (yellow) by Bronk Ramsey *et al.* of Egyptian dynastic chronology over the selected time interval. A large part (blank) of the Second Intermediate Period was not investigated owing to the lack of secure samples. (3) The ^{14}C results (yellow) (*14*) of various archaeological phases of Tell el-Dab^{c}a. (4) The much younger archaeo-historical dating (blue) by Bietak of the same phases (*13*, *14*). (5) The association of the Tell el-Dab^{c}a phases (*13*, *14*) with the young (low) Egyptian historical chronology (blue).

ogy for dynastic Egypt (*7*), it emerges that the Minoan Santorini eruption is older than the ^{14}C dates (both uncalibrated and calibrated) for the beginning of the New Kingdom (see the figure).

However, according to archaeo-historical dating, the eruption took place during the New Kingdom (18th Dynasty), around 1500 B.C.E. (*13–15*). The discrepancy between the two dating methodologies is also reflected by the two alternative dates for the Aegean Late Minoan IA archaeological period: (i) ca. 1710 to 1600 B.C.E. by ^{14}C dating (*16*) and (ii) ca. 1575 to 1480 B.C.E. according to archaeo-historical dating (*13–15*). The two deviating chronologies for the crucial Late Minoan IA period, during which the Santorini eruption occurred, show that one has to be very careful not to mix dates from one methodology (^{14}C) with the other (archaeo-historical), as it may lead to inaccurate archaeological and historical associations (*12*).

Tell el-Dab^{c}a, situated in the eastern Nile Delta, is a key archaeological site, having a detailed sequence of phases associated, respectively, with the Middle Kingdom, the 13th Dynasty, the Hyksos Period, and the 18th Dynasty (*13*, *14*) (see the figure). From the radiocarbon dating of short-lived plant material from many archaeological phases of Tell el-Dab^{c}a, a graphic overview of the calibrated ^{14}C results, after sequencing, was presented in relation to the stratigraphy (*14*). Comparison of these ^{14}C results with the ^{14}C investigation by Bronk Ramsey *et al.* of dynastic Egypt gives rise to a problem. Phases D1.2-1.1 of Tell el-Dab^{c}a are associated with the beginning of the New Kingdom, dated by Bietak (*13*, *14*) on historical-archaeological considerations to ca. 1530 to 1480 B.C.E. However, the calibrated ^{14}C age range for these strata, after sequencing, is ca. 1720 to 1640 B.C.E. (*14*), which is much older than the results by Bronk Ramsey *et al.* for the beginning of the New Kingdom, ca. 1550 to 1560 B.C.E. Hence, a time difference of ~90 to 170 years exists between two investigations for the beginning of the 18th Dynasty.

What is erroneous here—the ^{14}C dates by one study (*7*) or the other (*14*)? or the associations between the Tell el-Dab^{c}a archaeological phases and dynastic history, as the ^{14}C results from Tell el-Dab^{c}a are systematically older by ca. 100 to 200 years than the Egyptian historical chronology (*13*, *14*)? or the associations between the various funerary archaeological contexts from museum collections and dynastic history (*7*)? The last possibility seems unlikely, given the coherence between the ^{14}C dating results from multiple archaeological sources. On the other hand, Tell el-Dab^{c}a has detailed archaeological linkages with the Aegean and the Near East (*13*, *14*). Therefore, not only Tell el-Dab^{c}a is involved in this enigma, but the Middle and Late Bronze Age archaeology of the Aegean and the Levant as well.

The systematic investigation by Bronk Ramsey *et al.* marks a great step forward in the corroboration and refinement of Egyptian dynastic chronology with radiocarbon dating. However, much of the Second Intermediate Period, including the Hyksos Period, was not included in the above investigation, as secure samples are rare. Given the enigmatic ^{14}C dates from Tell el-Dab^{c}a, a key site in relation to the Second Intermediate Period and the beginning of the New Kingdom, it would be very important to conduct systematic radiocarbon research of multiple-source samples from the 13th Dynasty and the Hyksos Period. Moreover, ^{14}C dating of other Middle and Late Bronze Age archaeological sites in the region will enable association of archaeological strata with the new radiocarbon-dated Egyptian historical chronology (*7*), which may lead to a solution of the complex multidisciplinary problems in establishing a chronology for the second millennium B.C.E.

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